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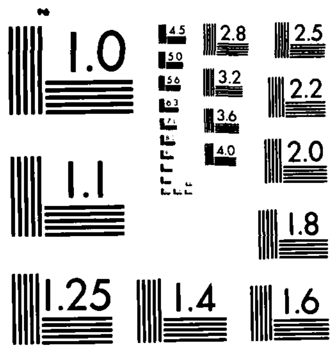
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THE THERMAL RESISTANCE OF THE CF CW SUIT

by

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ABSTRACT

The thermal resistance of the Canadian Forces chemically protective suit was measured from the heat loss of human subjects experiencing cold stress. The results are consistent with a simple calculation based on the measured resistances of the fabric layers and the estimated values for internal and external still air layers. No convective cooling attributable to body motion was observed although the exercise rate was low (walking at 2 km/hr).

RÉSUMÉ

La résistance thermique du vêtement de protection par agent chimique des Forces canadiennes a été mesurée en fonction de la perte de chaleur enregistrée chez des sujets soumis au froid. Les résultats obtenus viennent confirmer les calculs effectués à partir des mesures de résistance des couches de tissu et les calculs quant au pouvoir isolant des couches d'air internes et externes. On n'a pas observé de refroidissement par convection attribuable à l'exercice, bien que celui-ci ait été léger (marche à 2 km/h).

INTRODUCTION

In a previous note (1) the thermal and water vapour resistances of US, UK and Canadian suits were discussed in terms of a simple model of heat and water vapour flow in which air layers played a major role. Since that model neglected potentially important factors such as the variation of air layer thickness over the body surface and convective heat and mass transfer induced by body motion, it was decided to test the model in a physiological trial.

The model uses measured values of the thermal and vapour resistances of fabrics and estimates of the thickness of air layers to predict the thermal and vapour resistances of the complete clothing system. While in a real-life heat stress situation heat will be lost by both sensible heat flow and the evaporation of sweat, in a test of a model it is much easier to obtain a clear result if the two forms of heat loss are considered separately. Accordingly, it was decided, at least initially, to focus on sensible heat loss and conduct the experiments with the subjects suffering cold stress so that they would not sweat. Also it was desirable to keep the clothing as simple as possible. The CW suit was therefore worn over a single layer of a skin tight knit fabric (CF thermal underwear) of known thickness and thermal resistance, constant over the whole body. An even simpler alternative would be to have had no clothing other than the CW suit but this was rejected since the assessment of cold stress relies heavily on skin temperature measurements and, if significant air movement under the suit did occur, it might give rise to large deviations from a uniform skin temperature. In such situations, the accepted practice (suspect at the best of times) of deducing mean body temperatures from rectal and skin temperatures alone would certainly be erroneous. Inclusion of a uniform layer of insulation next to the skin can be expected to ameliorate such problems. The conditions of the experiment were not, therefore, very realistic but were designed to give an unambiguous test of the model which could then be used to predict heat losses in more realistic situations. Since real-life conditions are highly variable, the choice of particular conditions as being realistic is entirely arbitrary anyway. The more general information supplied by a model is more useful than are the results of a single realistic test.

METHODS

Four members of the CF/DREO test team volunteered to participate in the experiments. Their anthropometric characteristics are given in Table 1. Each subject had 12 YSI type 44004 thermistors attached to the skin using Blenderm Surgical tape (3M Company) at the various sites shown in Figure 1 and had a rectal thermistor probe inserted 15 cm into the anus. In addition he had thermistors attached to the mid and small fingers of the left hand and to the large toe of the left foot. The subject then dressed in the appropriate clothing which consisted of Canadian Forces winter underwear, balaclava, thin leather gloves, socks, running shoes and either a standard size CW coverall or a CW coverall modified for each subject so as to be as tightly fitting as possible consistent with unhampered walking. After dressing the subject walked around the observation area of the environmental chamber (ambient temperature = 22°C) for 40 minutes at approximately 2 km/hr after which he entered the environmental room which was set at either 5°C or -20°C ambient temperature and walked for 60 minutes on a treadmill set at 2 km/hr. Thus each subject had four exposures, i.e. modified suit at 5°C and -20°C and standard suit at 5°C and -20°C.

Temperatures were taken every minute by an automated data acquisition system (3497A Data Acquisition/Control Unit and HP85 Personal Computer, Hewlett Packard) which collected the resistance measurements of all the thermistors and converted them to temperatures via software. These readings were then stored on magnetic tape for subsequent analysis. Mean skin temperatures and mean body temperatures were calculated as in the following formulae (2,3):

$$T_s = .07\ T_1 + .085\ T_2 + .065\ T_3 + .085\ T_4$$
$$+ .14\ T_5 + .05\ T_6 + .095\ T_7 + .065\ T_8$$
$$+ .07\ T_9 + .09\ T_{10} + .09\ T_{11} + .095\ T_{12}$$
$$T_b = .67\ T_{13} + .33\ T_s$$

TABLE I

ANTHROPOMETRIC CHARACTERISTICS OF TEST SUBJECTS

Subject	Age	Mass (kg)	Height (m)
F	29	72	1.73
D	22	76	1.75
G	25	59	1.70
J	30	64	1.75

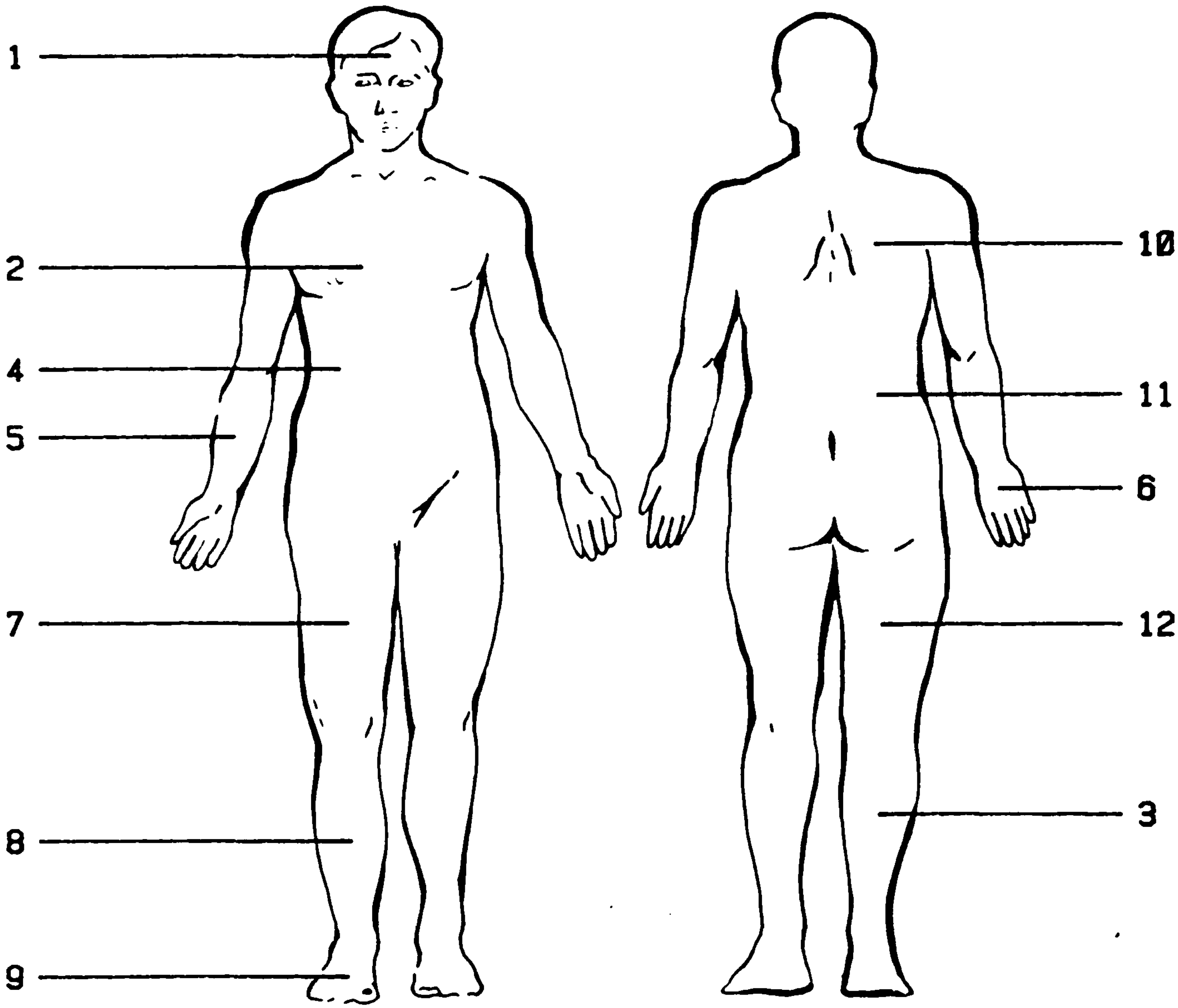

Figure 1: Location of Thermistors

where T_s = mean skin temperature
T_b = mean body temperature
T_1 = forehead temperature
T_2 = chest temperature
T_3 = rear calf temperature
T_4 = abdomen temperature
T_5 = lower arm temperature
T_6 = back of hand temperature
T_7 = thigh temperature
T_8 = front calf temperature
T_9 = foot temperature
T_{10} = upper back temperature
T_{11} = lower back temperature
T_{12} = rear thigh temperature
T_{13} = rectal temperature

Metabolic rates were measured using a Beckman Metabolic Measurement Cart (MMC). Each subject wore an aircrew chemical-biological mask from which all the breathing valves were removed. Hoses were attached to both the inlet and outlet breathing ports of the mask so that the air being breathed went through a one-way valve and down the two meter inlet hose to the mask. It then left the mask via the outlet hose to the outside of the environmental chamber where it passed through another one-way valve to the MMC. Metabolic rates were calculated every four minutes using the Beckman clinical exercise program.

In view of the rapid variation in skin temperature during the first part of each trial, thermal resistance values were calculated from the data collected in the period starting 15 minutes after entry into the cold room, and lasting for 45 minutes or until the subject requested termination.

The metabolic rate and skin temperature were averaged over this period and the initial and final body temperature taken according to equation 2. The resistance of the clothing was then calculated by

$$R = (\overline{T}_S - T_A)/\overline{Q} \qquad (3)$$

where

$$\overline{Q} = 0.9\,\overline{M} + C\Delta T_b \quad (4)$$

Here $\overline{Q}$ is the average heat loss rate per unit area

$\overline{T}_S$ is the mean skin temperature averaged over time

T_A is the ambient temperature

$\overline{M}$ is the metabolic rate per unit area averaged over time

C is the heat capacity per unit area of the body

and ΔT_b is the change in mean body temperature

Respiratory heat loss was taken into account as approximately 10% of the metabolic rate giving the factor of 0.9 in equation 4.

RESULTS AND DISCUSSIONS

The detailed results for metabolic rates and rectal and skin temperatures are given in Table II. The calculated resistances are given in Table III.

TABLE II

HEAT PRODUCTION RATES AND BODY TEMPERATURES FOR EACH TRIAL

SUIT	AMBIENT TEMP (°C)	SUBJECT	AVERAGE MET. RATE (W/m^2)	RECTAL TEMP INITIAL °C	RECTAL TEMP FINAL °C	MEAN SKIN TEMP INITIAL °C	MEAN SKIN TEMP FINAL °C	MEAN SKIN TEMP AVERAGE °C	PERIOD S
LOOSE	-20	F	110	36.90	37.00	27.0	24.1	25.4	2460
		D	68	37.37	37.37	25.5	22.4	23.7	2520
		G	138	37.52	37.59	27.2	24.2	25.3	2460
		J	57	37.13	37.00	26.0	24.5	25.2	1020
LOOSE	0	F	81	37.03	36.97	30.5	29.4	29.9	2460
		D	71	37.13	37.11	29.0	27.4	28.2	2460
		G	108	37.63	37.60	30.8	30.0	30.5	2460
		J	94	37.17	37.11	30.2	28.4	29.4	2460
TIGHT	-20	F	109	36.82	36.78	26.9	24.1	25.2	2460
		D	77	37.58	37.52	26.0	22.7	24.1	2040
		G	142	37.52	37.02	27.0	25.1	25.7	2460
		J	108	37.05	36.61	27.6	24.8	26.0	2460
TIGHT	0	F	86	36.93	37.04	30.4	28.7	29.5	2460
		D	73	37.36	37.23	28.2	27.0	27.4	2460
		G	119	37.68	37.61	30.3	29.2	29.6	2460
		J	102	37.06	37.02	29.1	28.3	28.6	2460

TABLE III

Experimental values of the thermal resistance of the tight and loose-fitting suits for each subject at two ambient temperatures.

SUITE	AMBIENT TEMP. (°C)	RESISTANCE (m^2K/W) SUBJECT F	SUBJECT D	SUBJECT G	SUBJECT J	AVERAGE $\pm$ STANDARD ERROR
LOOSE	-20 0	0.305 0.312	0.362 0.296	0.264 0.272	0.368 0.254	0.304 ± 0.015
TIGHT	-20 0	0.300 0.293	0.304 0.292	0.258 0.229	0.294 0.267	0.280 ± 0.009

TABLE IV

Expected thermal resistances based on fabric and still air layer values. (m^2K/W)

	TIGHT	LOOSE
UNDERWEAR	0.05	0.05
INTERNAL AIR LAYER	0.10	0.13
SUIT	0.05	0.05
EXTERNAL AIR LAYER	0.10	0.10
TOTAL	0.30	0.33

Each layer of clothing made of thin textile fabrics normally traps under itself a layer of air of about 5 mm thickness. In addition, at least in low wind conditions, an external air layer of about 5 mm thickness adheres to the outermost clothing layer. Heat travels across these air layers by radiation and conduction, each mechanism contributing about 5 W/m^2K, for an overall thermal resistance of 0.1 m^2K/W. For air layers of 10 mm or less, convection is unimportant unless driven by wind or body motion. The underwear and the CW suit material are both about 2.5 mm thick and each have intrinsic thermal resistances (determined on a Foundation Electronics HFMA101 conductivity apparatus) of about 0.05 m^2K/W. In the loose suit, the internal air layer is thicker, estimated as 10 mm for a resistance of 0.13 m^2K/W. Thus the expected total resistances are, as summarized in Table IV, 0.30 and 0.33 m^2K/W for the tight and loose suits respectively.

The experimental values from the physiological trials are about 10% lower than those predicted by the model with a random error of 5%. Even though the discrepancy is larger than the random error, the agreement must be considered remarkably good. The model is crude, as is the physiological model used to interpret skin and rectal temperatures. Thus, systematic errors of greater than 10% would not be surprising. The difference between the two suits is predicted to be 0.03 m^2K/W consistent with the observed difference of 0.024 ± .017 but the random error is too large for any conclusions to be drawn.

The agreement between the model and the experiments tends to confirm the basic assumptions. In particular, if body motion were to introduce significant corrective heat transfer within the clothing, one might expect the model to overestimate resistance by up to 0.1 m^2K/W. The observation is only one third of this. Heat loss by bellows ventilation, likewise, does not seem to be significant as it has been left out of the model without apparently significant error. Admittedly though, the walking speed of 2 km/h was low and such effects can be expected to increase with increasing velocity.

That the model predicts the thermal resistance correctly suggests that the water vapour resistance should also be correct as the two modes of transfer are in several respects analogous. However, such a conclusion must be tentative since a small amount of air motion may have little effect on sensible heat transfer yet a large effect on evaporative cooling. The quantity of heat that a volume of air can carry as latent heat of vaporization can be much larger than that carried due to the heat capacity of the air itself.

CONCLUSION

The value of thermal resistance of the CF chemically protective suit worn over thermal underwear was found to be consistent with a simple physical model consisting of alternating textile and still air layers. The experiments were not performed under realistic conditions but, since the model seems to be correct, model calculations can be made to give the sensible heat loss in a wide variety of conditions including suits worn over different types of inner clothing. The results would also suggest that model calculations of the evaporative heat loss can also be made with some confidence.

REFERENCES

(1) B. Farnworth and R.M. Crow, "Heat Stress in Chemical Warfare Clothing", DREO Technical Note 83-28 (1983).

(2) G.L. Hody, "The Field Measurement of Cold Stress in the Marine Evnironment". Consulting Report to the Defence and Civil Institute of Environmental Medicine, 1973.

(3) A.C. Burton and O.G. Edholm, "Man in a Cold Environment", p. 39, Edward Arnold Publishers Ltd., 1955.

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